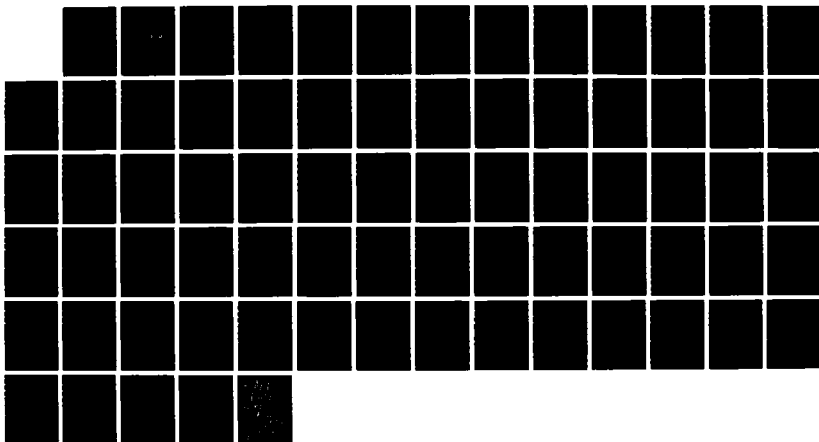
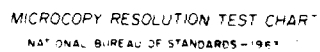


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FOR ENERGY-EFFICIENT (U) CONSTRUCTION ENGINEERING
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**US Army Corps
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Construction Engineering
Research Laboratory

USA-CERL TECHNICAL REPORT E-88/02

December 1987

Contracting, Construction, and Acceptance Testing
for Energy-Efficient Buildings

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Identification of Ways to Improve Military Construction for Energy-Efficient Facilities

by
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To meet goals for lower energy consumption at Army facilities, the U.S. Army Corps of Engineers (USACE) has altered its standard design guidance to include energy-efficient designs for military construction. However, energy-conscious design is only one component required in an overall plan to reduce energy needs at new facilities. Equally important are the quality of construction procedures and materials and the operation and maintenance methods used once the facility is placed inservice. Thus, it is necessary to control techniques, materials, and equipment as part of the Military Construction, Army (MCA) process to ensure that energy-conscious designs can be implemented successfully.

Based on surveys of the USACE construction community and installation new facility users, the U.S. Army Construction Engineering Research Laboratory (USA-CERL) has developed recommendations to improve the MCA procedure and ensure energy-efficient facilities. These recommendations include improving the quality control/quality assurance inspection process; requiring a comprehensive system-wide operating manual from the facility designer; and establishing a reliable acceptance testing procedure for HVAC systems. USA-CERL has completed preliminary work on an acceptance testing program.

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tive maintenance procedures for heating, ventilating, and air-conditioning (HVAC) systems require changes to ensure optimal function of this important component.

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FOREWORD

This work was performed for the Directorate of Engineering and Construction, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162781AT45, "Energy and Energy Conservation"; Task Area A, "New Construction Energy Design"; Work Unit 013, "Contracting, Construction, and Acceptance Testing for Energy Efficient Buildings." J. McCarty, CEEC-EE, was the HQUSACE Technical Monitor.

The work was conducted by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. G. R. Williamson is Chief, ES. The technical editor was Dana Finney, USA-CERL Information Management Office.

Appreciation is expressed to the Fort Riley, KS, Resident Office for assistance in determining the actual construction process for Military Construction, Army (MCA) facilities. Appreciation also is expressed to Rebecca Bromich and Michael Lorenz of the Kansas State University Department of Architectural Engineering for help in determining acceptance testing requirements.

COL N. C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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IDENTIFICATION OF WAYS TO IMPROVE MILITARY CONSTRUCTION FOR ENERGY-EFFICIENT FACILITIES

1 INTRODUCTION

Background

In response to Executive Order 12003¹ and a rapidly increasing utility bill, the U.S. Army has established a goal to have post-FY85 new construction consume 45 percent less energy than FY75 new construction. By FY95, an additional 10 percent reduction is required using FY85 as the base year. To meet this goal, the U.S. Army Corps of Engineers (USACE) has upgraded its design guidance to produce more energy-efficient facility designs. The improved guidance has tightened prescriptive standards, implemented design energy budgets for each facility, and required that rigorous energy evaluations be performed for new facility designs.

An energy-conscious facility design is critical to reducing energy consumption; however, equally important are the quality of construction procedures and materials, and the operation and maintenance (O&M) methods used once the facility is placed in service. For example, tightening the requirements for a facility's heating, ventilating, and air-conditioning (HVAC) system can significantly increase the potential for energy-efficient operation. Thus, it is necessary to control techniques, materials, and equipment as part of the Military Construction, Army (MCA) process to ensure that energy-efficient designs can be implemented successfully. Without this control, much of the design effort may be wasted through incorrect execution of the facility's energy-saving features.

The MCA process was developed before the new energy goals were issued. As a result, there is a need to update this process to ensure that all its components (i.e., contracting, specifications, quality management, and acceptance testing) support energy-efficient design. As part of this effort, the U.S. Army Construction Engineering Research Laboratory (USA-CERL), in a 1986 Interim Report, suggested preliminary recommendations to improve the MCA process.²

The Interim Report focused on the original purpose of this study, which was to improve the construction subprocess of MCA. During the investigation, however, it was discovered that many other facets of MCA affect the final product in terms of energy-efficient performance. For example, the design process can determine how energy-efficient a new facility will be, but variations in the design process can result in similar facilities having different levels of energy efficiency; the way in which a guide specification is edited defines the quality of the HVAC system and how it will be installed. These parts of the overall process are interrelated and must be considered on a wider scale than originally planned. Thus, the study was expanded to identify all processes of MCA that impact building energy efficiency and ways of improving them.

¹ Executive Order 12003, *Relating to the Energy Policy and Conservation* (July 20, 1977).
² D. Herron, D. Chu, and C. Burton, *Preliminary Recommendations for Improving the Construction and Acceptance Testing of Energy-Efficient Facilities*, Interim Report (IR) E-86/05/ADA169913 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], June 1986).

In gathering information from the field to support this work, it became apparent that the need for acceptance tests is critical. At present, there are no established minimum requirements for acceptance testing of HVAC systems. Moreover, USACE often lacks proper test equipment and trained personnel at many construction sites. The result is that acceptance testing often is restricted to a review of the Testing, Adjusting, and Balancing (TAB) reports submitted by contractors with no adequate means of verification.

Acceptance testing is mandatory for verifying that a new facility's energy-saving design is optimized. Without this guidance, all other efforts to improve the energy aspects of MCA would be meaningless. These tests must be relatively simple to conduct and must be designed to represent the entire picture based on a few diagnostic procedures. USACE quality assurance inspectors would be trained to do the tests.

Objectives

The overall objective of this study is to recommend revisions to the MCA process to ensure that facility contract documents, the construction process, and the resulting structure embody design energy conservation goals. This report addresses two phases of the objective: (1) identification of potential improvements to the MCA process which would increase building energy efficiency and (2) preliminary development of an acceptance testing program for HVAC systems.

Approach

The following steps were taken to carry out the objectives of this study:

1. Preliminary recommendations from IR E-86/05 were analyzed to narrow the focus of the investigation.
2. Field personnel involved in the MCA process were surveyed for views on the effectiveness of existing Army construction and contracting procedures in ensuring energy efficiency.
3. Trade publications were reviewed to identify problems similar to those in military construction and to evaluate potential solutions.
4. Construction of buildings was monitored onsite to identify any deficiencies in contract documents, specifications, and the construction process.
5. Specific recommendations for revising the MCA process were developed.
6. Existing techniques for HVAC system acceptance testing were analyzed for potential applicability to the Army; on this basis, proposed inspection checklists were developed.

The construction monitoring listed in step 4 above has seen slow progress due to unavoidable delays in the project. Because construction has not yet reached a stage at which meaningful information can be gathered, this step is not treated further in the report. When the project is completed in 1987, another report will present the results.

Mode of Technology Transfer

It is recommended that these study results be used to improve the MCA process and the design and construction documentation that define it. The acceptance test procedure to be developed in this study can be used directly by USACE field personnel in administering construction of new facilities, and by installation Directorates of Engineering and Housing (DEHs) in improving the operation of existing facilities.

2 IMPACT OF CONSTRUCTION QUALITY ON ENERGY EFFICIENCY

To determine what new procedures are needed to construct more energy-efficient facilities, USA-CERL contacted several USACE Districts and Field Operating Agencies (FOAs) by telephone or personal interview for detailed information (Appendix A). Interviewees were asked to express their opinions on construction quality--specifically, to identify any areas affecting the successful implementation of energy-efficient design. In addition, DEHs at some installations were asked for information on the overall quality of facilities constructed by USACE.

Recent trade publications also were reviewed to see if the private sector's experience in acquiring energy-efficient new facilities bears any similarities to that of USACE. Solutions proposed by industry were assessed for potential applicability to USACE construction.

Survey of USACE Construction Procedures

Information from the field indicates that, overall, construction quality is being maintained. However, some recurring problems were identified that potentially affect optimization of a facility's energy-saving features. These problem areas have been grouped into the following categories:

- New facility design
- Specifications
- Construction process
 - Contractor quality control/quality assurance (CQC/QA)
 - Testing, adjusting, and balancing
- O&M

Findings in each category are summarized below. *It is important to note that results presented here represent perceptions among USACE construction personnel and facility end-users. Not all information applies to all locations because each District and FOA has unique requirements. Thus, the findings are a compilation of repeatedly expressed opinions about facilities that have a wide range of missions. Many of the problems addressed here have been stated in previous studies, but their continued occurrence indicates solutions are still required.*

Design of New Facilities

Several comments were received on the design itself as well as the design process. Although this report is primarily concerned with the design impact on construction quality, the number of comments received on design merit brief discussion. The comments are grouped into three subareas: architectural design, design review process, and design feedback.

Design. An often repeated complaint about design was that it was not innovative enough or that it was inadequate in other ways. Heavy reliance on previously established designs may result in an inefficient facility with unnecessary duplication of features. Examples include the use of breakers to control other breakers or panels that control other panels.

Although there is nothing inherently wrong with USACE's standard designs, architect/engineers (AEs) may not always adapt them sufficiently for each individual project. These designs are not intended to be used "as is" without consideration for project and site requirements. For instance, USACE designs include options for the mechanical system, but these often are not incorporated into the final design. In other cases, a design may look good on paper but fail to work well in actuality. Other designs may have been based on past as-builts which were neither accurate nor up-to-date in terms of energy efficiency. Designs that do not meet installation-specific requirements usually require modifications later at a cost that defeats the purpose of using standard designs.

Another problem can occur with standard designs if locational and climatic variances are not considered. Depending on location, design temperature criteria can vary greatly for a "standard" design. For example, at one installation in the Southwest, even though evaporative cooling would have been a viable alternative, it was not specified in the standard design. Because of this, the AE did not consider it and instead used air-conditioning, which consumes more energy.

Some additional examples of the inadequate designs reported are described below:

- Some buildings have been designed for year-round climate control when this feature may not be required. At one installation, no heating or air-conditioning is required for 4 months of each year, yet some are not designed with operating windows.
- Equipment operating temperature has been designed for standard humidity. This design temperature was inappropriate for one installation in the Southwest with a very dry climate.
- In special buildings such as medical and dental facilities, air-conditioning equipment has been undersized, resulting in burnout. This design was too exact; some overdesign would have prevented future replacement costs.
- At another location, the furnaces have been oversized. In this case, the overdesign was not necessary.
- Specialized lighting equipment consisting of high-power fixtures with a backup system has been used on one building even though emergency lights had been installed.
- One building is well insulated, but has been designed with an uninsulated glass storefront facade positioned against prevailing winds. This design has negated all benefits from the insulation.

A common statement from O&M personnel was that buildings are designed with overly sophisticated controls. Many persons commented that these controls create more problems than they solve. For example, enthalpy controls designed for mechanical systems often are overridden by O&M personnel after turnover because the controls are

not believed to be designed or installed correctly. In other cases, controls for an economizer cycle are claimed to work poorly and sometimes not at all. Electronic controls also are perceived as too sophisticated and difficult to maintain. In many cases, electronic controls have been disconnected and replaced with pneumatic controls shortly after a new facility has been placed in service. Too little familiarity and training may be a reason for this lack of confidence. (USA-CERL is currently conducting research to help make HVAC controls simpler and easier to understand and operate.)

It is important to emphasize that not all design problems reflect faulty AE judgment. In many cases, the AE may not have enough guidance to produce a design that incorporates state-of-the-art energy conservation measures. Little information may be available to help the AE make acceptable tradeoffs. For example, a decision to prevent water damage due to condensation may be at the cost of allowing inefficient heat transfer. Another nebulous area is in deciding which of several available methods would be best for calculating wall heat transfer and losses. Without specific guidance, designers often are not sure which method will yield the most accurate results. Some designers have commented that more detailed guidance--broken down by building zones--is needed.

Restrictions at individual sites also may impact the energy efficiency that can be achieved. A new facility's orientation may be limited due to existing site constraints, making it impossible for the designer to locate the structure in the best possible configuration from an energy-savings standpoint.

Finally, and perhaps most important, is the role of economics in design. An AE's final design choices are almost always dictated by initial cost, which may limit the possibilities for energy conservation. To acquire the flexibility needed to take advantage of many design options, the AE must make careful cost/benefit predictions for the life of the facility--including estimated savings due to better energy efficiency. The higher first costs typical of energy-efficient buildings must be justified over the long term.

Design Review Process. Many users claimed that the design review process is inadequate for some projects. It was held that USACE design reviewers may lack familiarity with individual job conditions; moreover, highly qualified reviewers often do not have enough time for a detailed review of the final design. Therefore, users would like to have a greater role in design review.

At one installation, the DEH's engineering and planning departments were allowed to review submittals at the 30 to 35 percent design phase. However, at this point, mechanical design often had not yet begun. The 60 to 65 percent level was believed to be a better point for input to the review. At another installation, the DEH's master planning department reviewed MCA projects but the engineering department did not. The engineers believed they should be allowed to review, but admitted this would increase their already heavy workload.

Personnel turnover at an installation also can affect progress at this stage as well as during construction. Rotation of base planning personnel may result in original planners being transferred before project completion; if their replacements request changes, progress is delayed.

Many interviewees also felt that coordination of review efforts between USACE and the user could be improved. Several DEHs stated that they have too little input concerning real needs and operating conditions; they thought their installation design section should have much more input. At one installation, there was coordination

between DEH and USACE during the design phase, but this ended after construction began. Responses indicated that the extent of coordination depends on local practices and varies with each location.

Design Feedback. There was general agreement that better communication is needed for feedback on construction and design deficiencies. Some Districts maintain a list of repeated deficiencies, but this system is informal. With no official feedback system, lessons learned by implementing a design at one installation are not being passed on to others. As a result, the same design and construction problems may recur at different installations.

Specifications

Another subject generating a large number of comments was specifications. The specifications used in USACE projects can be subdivided into three types: contract, guide, and reference. These three groups are interrelated and can have varying degrees of impact on each other. In addition, requirements in the guide specifications for testing and balancing eventually are incorporated into the contract specifications, where they may have a direct effect on final construction.

Contract Specifications. Specifications that contractors must follow for military construction can differ greatly from commercial construction specifications. This situation can create problems for contractors who are unfamiliar with military construction. Some interviewees suggested that ambiguity in the specifications is the main reason these problems occur; specifications may be too general and, as a result, subject to misinterpretation. In other cases, the specifications may provide too much information, with contradictions occurring in the requirements.

Another assertion was that the contractor expects contract documents and drawings to be matched perfectly, which may not be realistic. A lack of coordination between drawings and specifications was reported in some cases. When "as indicated" in the specifications is not really indicated on the drawings, the contracting officer's authority is weakened in specifying where the components should be placed. Consequently, components may not be installed in the most desirable location or, for lack of guidance, may be overlooked. While important, the drawings should not receive emphasis at the expense of well written specifications. A balance is needed in coordinating these areas.

To lessen the possibility of misinterpretation, the specifications need to be very exact and clear. They should also be kept as brief as possible. If a specification is too long because it contains unnecessary or redundant material, the contractor may avoid reading it.

Guide Specifications. Several persons interviewed expressed the opinion that Corps of Engineers Guide Specifications (CEGS) could be more accurate; moreover, reliance on these specifications is sometimes too heavy. Although guide specifications were claimed to often provide too many options, it was also noted that designers may fail to select options or may misapply them--they may not always take time to delete inapplicable or unnecessary items with a thorough edit of the document. When all options are retained and incorporated into the contract specifications, the contractor may choose the cheapest--and not necessarily the best--alternative. The guide specifications must be tailored carefully to the specific project to reduce this possibility. All required information should be presented clearly and concisely.

The need for timely updating of guide specifications was also cited. The current process is considered too slow compared with procedures for updating industry standards.

Despite these perceived problems, proper use of guide specifications saves time and effort. Private sector specification writers usually have high regard for USACE guide specifications due to the coverage and completeness therein. Reviewing and improving the contents of the guide specifications may avoid some of the drawbacks cited by interviewees.

In terms of energy efficiency, the specifications usually lack exact guidance; the emphasis typically is on building function. Efficiencies for individual HVAC components such as motors, fans, boilers, and furnaces are often shown on the drawings as part of the equipment schedule, but this is not true in every case. A positive step toward upgrading the CEGS would be to require that HVAC component efficiencies be shown on the drawings or included in the specifications.

Reference Specifications. Some persons reported that, while reference specifications can be very detailed, they also may use the term "or equal," which can destroy the value of the specification. Another contention was that some industrial references are vague or contain too much cross reference to other sources.

Keeping a library of reference specifications apparently creates difficulties for some field offices, which stated there is too much unnecessary material and something more basic is needed.

Some respondents noted that contractors should keep a supply of all references needed for the type of work performed. Other field offices argued that neither they nor their contractors have the resources for keeping all reference specifications. When references are not readily accessible, construction delays may result as the appropriate source is located and delivered to the site for reading.

Testing. Some USACE field personnel indicated that the CEGS, and consequently the contract specifications, do not state clearly enough what the agenda should be for TAB. General testing requirements are given, but not specific ones. All specifications are more or less similar in the amount of detail listed for TAB. To clarify the contractor's responsibility, some field offices write their own testing requirements. (Additional problems with the TAB process are discussed under Contractor Quality Control/Quality Assurance below.)

The specifications need to identify clearly what the TAB will involve. However, highly detailed instructions on procedures such as efficiency calculation should not be necessary because this information usually is provided in the references.

Construction Process

The construction process is another area for which respondents suggested improvement is needed. Much of the problem was claimed to be due to the production orientation of construction which often emphasizes rapid completion at the expense of quality. This situation can have an adverse impact on the way in which HVAC systems are installed. Careful quality control during, and acceptance testing at the end of, construction are necessary to prevent future operating problems. This QC is especially important with regard to energy efficiency. By emphasizing quality in day-to-day construction work, deficiencies that are difficult to detect in a performance test or balancing procedure will be limited. An example of these deficiencies is improperly

insulated HVAC piping or ductwork which is situated in an inaccessible area; testing may not reveal the component's condition, which will adversely affect the energy efficiency of the HVAC system.

The CQC/QA process used in USACE projects has already been described in IR E-86/05. Acceptance testing is a separate concept by which USACE inspectors can verify that the work performed by the contractor is acceptable. It is not the same as TAB, which is the contractor's responsibility. At present, however, no formal USACE acceptance testing procedure exists.

Comments on the construction process can be divided into two parts: CQC/QA and TAB.

Contractor Quality Control/Quality Assurance. Most respondents agreed that CQC is a good idea but hard to enforce. Many large construction companies have a very good CQC staff, but many others do not. One problem is that it is unrealistic to expect contractors to inspect and, if necessary, disapprove their own work consistently. With large contracts, it can be difficult to ensure that the contractor appoints a large enough CQC staff to adequately carry out its assignments. With some contractors, the CQC manager may also be the project supervisor, leading to possible conflicts of interest.

Many interviewees said the CQC inspector should not be working for the contractor. Inspectors at risk of losing their jobs by being too conscientious will almost never provide impartial judgment. In addition, the CQC appointee may not be qualified to make proper inspections. Although USACE can insist that the contractor try and provide good CQC inspectors, the best solution was proposed to be more, better trained USACE personnel to inspect the CQC work (i.e., better QA). To make the system work, USACE must maintain close, consistent monitoring of the CQC. Also, the daily CQC reports must be reviewed thoroughly for completeness and checks on progress.

Responses to the USACE QA system were mixed. At some locations, it was held that the general MCA system has worked well because most contractors realize that it costs more to do a job over than to do it correctly the first time. Other respondents expressed the opinion that USACE construction inspectors often cannot do adequate inspections because they have too heavy a workload and cannot be thorough enough.

Although none of the interviewees indicated that they had a shortage of manpower, they did have some concerns about the qualifications of their staffs. Varying rates of personnel turnover within Districts and FOAs cause job information to be lost among the continuously changing mixture of civilian and military workers. Continual retraining is needed for their replacements.

Another problem is the lack of expertise that field personnel may have with HVAC systems. This problem can worsen as the complexity and sophistication of HVAC design and technology increase. Increased training to improve familiarity with the HVAC guide specifications among field personnel can help resolve this inadequacy.

Some USACE personnel noted that field inspectors, even when highly qualified, have no enforcement authority. Their demands must be taken seriously; thus, there is a need to establish rules and enforce them.

To reinforce its QA role, one area office makes extensive use of a video recorder. Once each week, a project inspection is videotaped. The contractor and subcontractors are notified so that they can be present if they wish. The entire inspection and all

discussions are recorded and kept in a library. This visual record of project inspections has eliminated most claims of misunderstanding and has been useful when court action has been necessary.

Testing, Adjusting, and Balancing. Primary responsibility for TAB is the contractor's. Normally, the TAB work is done by a subcontractor because the contractor usually does not have an appropriately trained staff. The procedures used can vary among different areas and even among different projects at a single location. The contract usually calls for the contractor to submit a proposed testing program at least 10 days before tests begin so that the contracting officer can review the procedures and instruments to be used as well as check the TAB staff's qualifications. This procedure saves time later because any problems can be addressed before the TAB work begins rather than causing interruptions due to some inconsistency discovered during testing. An additional requirement in most contracts is for the contractor to notify the contracting officer 2 days before any actual testing begins. This notice allows USACE personnel to be onsite for observation of the testing. Finally, the contractor is responsible for submitting completed report forms with test data and the final settings for various system components. USACE personnel review this information. Suspicious results can be questioned at this time and, if necessary, a complete or partial retest demanded.

USACE personnel responses to USA-CERL's questions about TAB work revealed a wide variety of existing practices. Interviewee perceptions of their installations' experiences with TAB are summarized below. These findings provided input to the development of acceptance testing recommendations for HVAC systems.

Specifications Requirements. Specifications that require TAB work to be performed in accordance with standards set by Associated Air Balance Council (AABC), National Environmental Balancing Bureau (NEBB), or Sheet Metal and Air-Conditioning Contractors National Association (SMACNA) reportedly provide the resident engineer with more authority than do those with generalized requirements. The AABC, NEBB, and SMACNA standards outline appropriate procedures, instrumentation, and test reports. They are accepted by industry, easily available, and contribute to the reliability of TAB work.

The specifications usually require TAB firms to be certified by either AABC or NEBB. When a TAB firm is not certified, it must prove that it is qualified under terms listed in the specifications. Many USACE personnel interviewed said that allowing noncertified firms to do TAB work is undesirable because performance qualifications are too general. In almost all cases, certified firms were preferred over those not certified. However, one resident engineer expressed the opinion that requiring a firm to be certified guarantees only a higher fee - not necessarily better quality work.

Contractor's Testing Program. USACE personnel were asked about the timeliness and completeness of the proposed testing program. Responses indicated that, although there is seldom 100 percent compliance with requirements for this proposal, most contractors submit something. Comments from some installations suggested the programs can be very general and not job-specific. At other locations, such general proposals are not accepted. If deemed necessary, the TAB personnel are not allowed to begin their work until USACE reviewers are satisfied. This practice varies according to the experience of the area office and the amount of detail given in the specifications. Problems within the program that may delay testing include inappropriate or uncalibrated instruments and a test plan not suited to the project.

The 2-day advance notice prior to testing usually is provided. In a few cases, some TAB subcontractors are lax in meeting this requirement. In others, the subcontractor notifies the general contractor instead of USACE; the general contractor then must notify the area office. If the USACE inspector does not know about the TAB and misses it, USACE will have no way to verify the accuracy of the TAB report. However, since most jobs are visited regularly at this stage of construction, the area office is generally aware of when testing will begin.

Many interviewees expressed that allowing the contractor to be responsible for TAB is the greatest drawback to current acceptance testing practices. Several FOAs said that, if possible, TAB should be on a subcontract separate from the mechanical contractor's. Only in this way can USACE expect to receive impartial results.

TAB Verification. Determining the reliability of TAB work is attempted in several ways, including consideration of past experiences with the TAB firm, close scrutiny of actual testing, and spot-checking the system with TAB instruments.

In many locations, certain TAB firms are used repeatedly on USACE projects, either through the contractor's preference and/or lack of availability of other firms. By observing a firm's performance on several projects, the contracting officer can determine if the TAB work is being done effectively. Repeated observations of properly performed tests, well documented procedures and test reports, as well as few user complaints in occupied buildings balanced by the firm indicate a well run and professional organization. In these cases, the area office may decide that little observation is required during TAB. Conversely, a poor track record for a firm's work indicates greater USACE involvement is required.

USACE personnel observe the TAB work at most projects. Many times, the observer is present for only part of the testing. Time constraints and number of personnel relative to workload usually preclude observing the entire testing process. Even when a USACE observer is present during the entire job, it can be impossible to monitor all areas of the testing. Usually, a team of TAB personnel is used to perform TAB. Because these individuals may be gathering data simultaneously from various parts of the system, a complete observation of everything being done is virtually impossible. Therefore, the usual USACE practice is to observe basic testing procedures and instrumentation.

Some interviewees reported that, occasionally, no observation is conducted. Several reasons were given for these cases, including: (1) not being notified when the testing will start; (2) inadequate number of USACE personnel available; and (3) lack of time. More positive reasons for no test observation are cases for which the contractor and TAB subcontractor have a proven, consistent record of quality work as discussed above.

Sometimes USACE personnel conduct spot checks with TAB instruments. However, these inspections are primarily done when problems arise or when there are questions as to how well the TAB work was performed. There is no standard procedure by which certain readings can be taken consistently on all projects. Moreover, the range of instruments available among the area offices is quite varied. Some locations have a relatively complete set of instruments whereas others have none at all. In some cases, the District office has instruments available to loan to area offices. Another potential source for instruments is the local DEH. Appendix B proposes a list of standard instruments for inspecting TAB work. Although it may not be practical for field offices

to have all these instruments, USACE field personnel should at least know what each one does and how it operates.

TAB Reports. Results of the TAB work as well as final settings of system components are submitted to the contracting officer on appropriate forms. Some USACE personnel reported having had problems with these TAB reports in some cases. The most common shortcoming is incomplete test results. Another problem occurs when the test data agree so well with design specifications that they look suspicious. In either case, a partial or complete retest may be demanded. Suspicious readings can be spot-checked as discussed earlier. Interviewees suggested that the best way to avoid such problems is to have the area office supply a detailed explanation of requirements prior to testing, combined with careful monitoring of the tests.

TAB Results. Most installations interviewed by USA-CERL are satisfied with the new facilities they have received. However, considering that energy often is not a serious concern of a facility's occupants, it is difficult to determine accurately, short of installing measurement instrumentation, how the HVAC systems are performing in terms of energy efficiency.

Although construction quality in general may be good, there is nothing to indicate that current inspection procedures produce HVAC systems which operate at optimal efficiencies. Rather, it appears that determination of a properly functioning system by USACE personnel is more often done qualitatively than quantitatively. Although the TAB firm provides quantitative information in its reports, the accuracy of these data depend on the qualifications of the firm and on the level of monitoring by USACE. Lack of care in gathering data, especially in crucial areas such as wet and dry bulb temperatures across a coil, can produce results that grossly misrepresent the system's actual operation.

It is not feasible for USACE to gather all the data required in a TAB job just to verify the reports. The manhours required to carry out this task are estimated at 33 per 20-ton system, 40 per 50-ton system, and 120 per 100-ton system.³ Area offices have neither the time nor personnel required for this work. The current emphasis is on ensuring a workable system rather than making a detailed analysis of how efficiently it operates. Observations are limited to verifying that valves open when switches are turned on and that the system responds to changes in the thermostat settings. The evenness of heating and cooling in the building is used to indicate how well the system is balanced.

Operation and Maintenance

Upon completing construction and turning over the finished facility to the installation, most of USACE's responsibility ends. USACE's job is to provide an operational facility and to guarantee its quality. USACE has no control over subsequent O&M of the new facility; that task is left to installation personnel.

The quality of the facility's design and construction helps determine the ease of operation and maintainability; in addition, qualifications of the installation maintenance personnel are important, as is treatment by the occupants. Deficiencies in any one area can lead to premature deterioration of the facility.

³J. Gladstone, *Air Conditioning Testing Adjusting Balancing, A Field Practice Manual* (Van Nostrand Reinhold, 1981), Ch 19.

Maintenance. Facility users want a design tailored for easy O&M after turnover. Many installation O&M managers complained that some designs are too complicated to maintain. In particular, some controls are too sophisticated for the managers' level of training (e.g., electronic controls as mentioned earlier).

Most installations said they would like more guidance on systems O&M than is typically received. New buildings require some type of all-inclusive operating instructions because the O&M personnel turnover often is so rapid that there is not enough time to teach them complete theory and practice. Classes on state-of-the-art mechanical systems could be a great help, to include basic instructions on how the equipment works.

Another problem plaguing effective O&M is the personnel shortage at many installations. Some DEHs reported having no one to maintain even the best, most efficient designs. Sacrificing personnel or preventive maintenance to save dollars may result in costly repairs later.

Personnel. DEH personnel at some installations said their shops have difficulty maintaining some equipment due to (1) lack of training and (2) heavy workloads. Some installations designed with energy-efficient components may be difficult to maintain because many District and field personnel are civil works oriented. Energy specialists or inspectors with energy-related knowledge are needed to supplement the staff.

Occupants. A facility may be designed, constructed, and maintained correctly, but still not function properly because of unauthorized tampering by its occupants. Many buildings' HVAC controls reportedly have been bypassed or had their settings changed by tenants who found the environment uncomfortable. For example, some occupants pulled the pins on the night setback because they did not understand its function. At one installation, 80 percent of these were disconnected within 1 week after turnover. At installations located within moderate climates, occupants apparently are not as likely to tamper with the mechanical system. Nevertheless, all occupants need to be educated about the reasons for having certain types of controls.

Survey of Private Sector Construction

The literature was surveyed to compare trends in private sector construction with those of the military. Findings are described under the same general categories used in the previous section.

As with the Army, problems in private construction are not concentrated in one area. A survey of 493 owners of construction projects with a median design budget of \$16 to \$25 million found that faulty construction was not always caused by poor construction procedures. While the most common problem, leaky roofs, was blamed on poor workmanship, the second most common problem, faulty HVAC systems, was most often the result of inadequate design. Project delays were most frequently blamed on contractors, but cost overruns were usually caused by the owners' change orders."

"Owners Lax on Project Control," *Engineering News Record* (9 May 1985), p 48.

Another source cites additional reasons for conflicts, disputes, and claims.¹ Some of these are:

- Different or conflicting interpretations of the plans and specifications
- Incomplete plans and specifications
- Unrealistic plans and specifications for specific project applications
- CQC/QA methodology that allows engineers and contractors to inspect and evaluate their own work
- Delays due to contract administration
- Increased competition to obtain the planning, engineering, and construction of the project at the lowest cost.

It is evident from this list that many of the problems occurring in the private sector parallel those in military construction.

Design

The adequacy of design has an important influence on final construction quality. Design inadequacies may arise because engineers responsible for planning and design have little or no construction experience.² Designs that are unclear or impractical will create difficulties for both the contractor and the construction QA representative. Another problem is that structural, civil, mechanical, and electrical designers often have a tendency to work independently within their own disciplines such that individual systems or parts of a project are designed without full consideration for total project constructability, operability, and maintainability.

Personnel with construction experience should be involved early in the design process to provide advice on the practicality of a project.³ Greater coordination and feedback are needed between the construction site and the design office. In some cases, individual designers may have enhanced knowledge due to some specific experience, but it may not filter down to the design organization. Having a structured feedback loop from field construction activities to the system would improve constructability and make quality control easier.⁴ Proper consideration for O&M also should be given by involving the facility's future operators early in the design process.⁵

¹K. P. Buehert, "Conflicts and Disputes: Are We Organized to Handle Them Effectively?" *Quality in the Constructed Project* (American Society of Civil Engineers [ASCE], 1985).

²K. P. Buehert.

³C. N. Dunnam, "Dealing With Constraints Affecting Construction Quality," *Quality in the Constructed Project* (ASCE, 1985), pp 163-164.

⁴D. J. Duck, "Organizing and Managing for Quality Construction," *Quality in the Constructed Project* (ASCE, 1985), p 112.

⁵C. N. Dunnam, p 164.

Construction Process

Although there is a great deal of dissatisfaction with the CQC/QA concept, it should result in acceptable projects if implemented properly. Many persons have argued that using current CQC/QA methods has increased claims, litigation, and costs and decreased quality. They believe that allowing contractors to inspect their own work instead of having it done by an independent third party results in marginal quality work.¹⁰ Contractors are oriented toward profit and production rather than quality. Since the contractor is the only party in the construction process with direct control over construction quality, the quality will be lowered if the company's profit margin decreases.¹¹

On the other hand, contractors should be completely capable of doing quality work because they are directly in control of quality. Thus, the role of QA is to ensure that contractors know their duties. They should be given clear definitions of quality requirements, acceptable criteria, and inspection procedures to be used. The procedures should be described clearly in written form with instructions stating who is responsible for which procedures and how the work should be documented.¹²

If done correctly, CQC can result in faster, more efficient construction. A contractor responsible for inspection can work at a chosen pace and not be encumbered as much by having to wait for inspections from an outside party.¹³ Clearly, the contractor is being assigned a high level of responsibility here.

With CQC, the contractor is expected to submit and follow a quality control plan. However, one writer claims that review of the contractor's quality efforts often is limited to a look at the documentation; monitoring and verification of field personnel or procedures is rare.¹⁴ The same writer also believes most contractors are not in a position to properly train, supervise, and manage quality control personnel. The problem may be partially caused by the low bid system- according to that author, "lesser quality goes hand-in-hand with low price." Another cause is the need to meet project deadlines. Certain CQC activities can slow or delay work, so these may be neglected if QA is lax.¹⁵ In the end, a low-quality facility may be accepted with correlative credit because removal and rebuilding of inadequate portions may not be fully justifiable.¹⁶

The contractor's documentation of quality control requires close monitoring to ensure that all required tests and inspections have been completed. In addition, documents should be checked to ensure that tests/inspections have not been reduced in frequency from specification requirements. The contractors' reports should be accurate, showing both "pass" and "fail" results.¹⁷

"A Summary Report on the ASCE Workshop: Quality in the Constructed Project," *Quality in the Constructed Project* (ASCE, 1985), p 7.

D. J. Duck, p 110.

"A Summary Report on the ASCE Workshop: Quality in the Constructed Project."

R. L. Robbins, "Contractor's Quality Control Programs," *ASCE Journal of Professional Issues in Engineering*, Vol 110, No. 3 (July 1984), p 125.

M. Isaak, "Contractor Quality Control: An Evaluation," *ASCE Journal of the Construction Division*, Vol 108, No. C04 (December 1982), p 481.

M. Isaak, pp 482-483.

R. L. Robbins, p 126.

M. Isaak, p 483.

Careful control of submittal review is essential to keeping a project on schedule. Unnecessary submittals, such as those reporting information on equipment and materials already described in the construction contract, should not be allowed. This practice may reassure the contractor, but it can also produce inadvertent conflicts between the submittal and the construction contract. The submittal process should be managed carefully to prevent use of submittals to implement substantial changes in construction, thus bypassing change orders.¹⁸

Submittals should be reviewed as quickly as possible to avoid confusion, delay, added cost, and increased liability to all parties in the contract. Reducing the technical content of submittals, defining the time allowed for review, and eliminating superfluous material can minimize these effects.¹⁹

Operation and Maintenance

New owners sometimes overlook O&M requirements of a completed building. Neglected O&M eventually results in problems that do not occur when a building is given proper care. Two steps can be taken to improve this situation. First, the building operator should be fully trained to handle upkeep and any maintenance problems that arise. If operators are unfamiliar with or confused about a building's systems, they may disconnect or bypass components critical to building energy efficiency.

Second, a full set of O&M manuals should be provided for the building. Often, the documents issued do not thoroughly explain the building's important operating instructions and required maintenance procedures and intervals. Providing the owner with an all-inclusive O&M manual can help alleviate this problem. The manual should explain the building makeup, its various systems and components, proper operation, and required maintenance procedures and intervals. In addition to listing equipment O&M instructions, suppliers' names and addresses, and components, other topics might be how equipment is interrelated with systems, what functions equipment and systems are to perform, what conditions are to be maintained, how to know when a system is operating properly, troubleshooting procedures to be performed during system failure, proper sequence of operation, and a preventive maintenance program. Additional information can include design criteria as well as system and component capabilities, capacities, and limitations.²⁰

Responsibility for producing the O&M manual usually is the contractor's, but it might be better prepared by the designer. Since the designer creates the system and is ultimately responsible for its performance, it is logical that he or she is in the best position to tell the owner how to operate and maintain the system as designed.

¹⁸L. B. Dunlap and D. M. O'Malley, "Management of Submittals to Reduce Liability," *Proceedings of the Specialty Conference, Reducing Risk and Liability Through Better Specifications and Inspections* (ASCE, 1982), pp 22-23.

¹⁹L. B. Dunlap and D. M. O'Malley, p 24.

²⁰M. J. King, "Who Should Prepare Operating and Maintenance Manuals?" *The Construction Specifier* (July 1985), pp 24-25.

R. A. DiPasquale, "Division 17: An Owner's Guide to Maintenance," *The Construction Specifier* (March 1986), p 37.

3 RECOMMENDED IMPROVEMENTS TO THE MCA PROCESS

To obtain energy-efficient new facilities, some of the problems identified in Chapter 2 will have to be resolved. Based on findings from the surveys of field personnel and the literature, improvements are recommended to the following areas: design, specifications, bid process, construction process, and O&M.

Design

USACE standard designs should be used to minimize the amount of time spent designing new facilities; however, these designs should be adapted carefully to the needs and climate of the installation where the facility will be located. In particular, more attention should be given to the suitability of the HVAC system, both during design and design review.

Input from users is important since the users are familiar with the climatic and physical requirements of the site and with the ability of their staff to operate and maintain the designed system. A feedback mechanism among the design, construction, and operations phases is needed. A conference between all parties during concept design can give each party the opportunity to voice requirements and allow potential differences to be resolved. Another conference after turnover of the finished facility can identify problems and differences encountered during the project; the lessons learned can be recorded for future reference.

Controls should be designed for easy O&M. Overly sophisticated controls should not be specified unless they have a proven record of reliability and easy use. USA-CERL is developing a set of simplified design instructions and guide specifications for HVAC controls. For more information on this research, contact Dale Herron, USA-CERL, Energy Systems Division, P.O. Box 4005, Champaign, IL 61820-1305, telephone (217) 373-7278 (COMM), (800) USA-CERL (out of state), or (800) 252-7122 (in Illinois).

Specifications

Coordination between the designer and the specifications writer should be increased at all phases of the design process. This improvement will help prevent later occurrence of conflicting or insufficient information.

Guide specifications should be considered as guides only. Using them to produce construction specifications does not mean they need only a brief edit. All inapplicable items must be deleted and, when necessary to ensure an appropriate and properly working HVAC system, additional information that was not in the original guide specification should be added. Reference specifications should be used carefully. Citing too many references can create confusion and contradictions. The specifications writer should verify that the reference does, in fact, specify what was intended. In some cases, it may be better to incorporate the citation into the contract specifications instead of referencing it. Besides reducing the number of references, this step would also make it easier for both the contractor and the USACE inspector to interpret the contract.

The need for timely updating of guide specifications was cited frequently. However, this task should no longer be a problem because an automated system for managing the CEGS has become available. The system, called SPECBASE, is being

maintained on the Control Data Corporation (CDC) CYBERNET computer. Users can now obtain up-to-date guide specifications by logging onto CYBERNET and entering SPECBASE. Individual specifications can be easily downloaded to local computer systems or even personal computers for editing and conversion to contract specifications. It should be standard policy for all USACE specifications writers to use only the latest version of each guide specification.

At present, reference specifications often present storage problems, but advancing technological developments in optical disks used to store data will make this problem obsolete. Both the Government and private industry are working on automated systems to handle this massive amount of information.

Construction Process

Since current policy requires the contractor to assume primary responsibility for construction quality, USACE must strive to ensure that the CQC representative is fully qualified to perform inspections. If that person is not qualified, USACE must require the contractor to find a qualified replacement. USACE must emphasize to the contractor the importance of having qualified CQC inspectors. At the same time, USACE's QA inspectors must be fully qualified to verify the CQC efforts. To provide the best QA inspectors, USACE staffs should be provided with maximum training opportunities to place them at a higher level than their private sector counterparts.

TAB requirements for HVAC systems must be consistent for all MCA projects. This improvement will increase USACE inspectors' familiarity with the requirements. These personnel also should be trained well so that they will be able to easily understand TAB reports. Simple methods for verifying the reports should be developed for USACE field inspectors. Installation of temperature, pressure, and flow measuring devices on mechanical systems would be useful in determining how efficiently a component such as a boiler or chiller is operating. The cost of installing these devices compared with the overall cost of a project is minor considering the beneficial information that will be provided.

Operation and Maintenance

Although contracts require that operating instructions be provided to the user upon turnover of a completed facility, the information usually is limited to instructions for individual components and are not detailed enough for a complete understanding of overall system operation. An operations manual should be compiled that describes how all the various components of the HVAC system work together and how each individual component works in relation to the others. Especially important would be a section on operating and maintaining the controls since these devices usually create the most problems for the installation's maintenance personnel. Standards should be established for compiling the O&M manual.

Finally, a regular training program should be established for maintenance personnel. The program should provide adequate instructions on maintaining and repairing simple as well as sophisticated controls.

4 DEVELOPMENT OF ACCEPTANCE TESTING FOR HVAC SYSTEMS

A major goal of the Army is efficient use of resources. While current construction practices may result in working HVAC systems, these systems may not necessarily have maximum energy efficiency.

In IR E-86/05, USA-CERL analyzed an existing USACE HVAC guide specification (CEGS 15805, *Air Supply and Distribution System*) to determine if it provided adequate guidance for maximizing a new facility's energy effectiveness. Based on this analysis, a new Section 19 on TAB was proposed to replace the corresponding one in the CEGS. (See Appendix B in the Interim Report.)

Comments from USACE personnel who have reviewed the revised Section 19 indicate that its level of detail is too great. One problem is that the revision would increase the volume of the guide specification even more. Another contention is that the detailed instructions in the revised specification are redundant and therefore not necessary. Many respondents stated that, if contractor representatives performing TAB work are fully qualified, there should be no need to list their responsibilities in the contract specifications.

The current Section 19 already requires TAB to be in accordance with standards of AABC, NEBB, and SMACNA. However, it does not identify which sections of these standards apply. Since many USACE field inspectors do not have an extensive background covering mechanical systems, USA-CERL's intent was to give them a clearer idea of the steps involved in TAB. Once the inspectors know what is required of the TAB contractor, they should be better able to ensure that TAB is done properly. As the specification is now written, if USACE inspectors are not familiar with TAB procedures they will not be able to determine if the necessary work was completed.

Based on the responses from the field, however, making the specifications more detailed in terms of requirements may not be the best approach. Clearly, it is not USACE's role to verify a building's performance step-by-step; that would defeat the purpose of the CQC/QA concept. Thus, as mentioned in Chapter 3, USACE inspectors need a simple, standardized acceptance test procedure for HVAC systems. This procedure would not replace present TAB work, but rather serve to verify key areas that can provide a quantitative measure of HVAC system efficiency.

Acceptance testing of HVAC systems is a vital step in the construction of an energy-efficient building. This step gains importance as the size and complexity of the building increase. With smaller, residential-type structures, the heat loss due to conduction and infiltration through the building envelope dominates energy concerns. For larger buildings, the envelope plays a smaller role as internal loads such as lights, equipment, and occupancy as well as HVAC system efficiency become increasingly significant.

To facilitate development of acceptance testing for HVAC systems, a working definition of the term was needed. The definition which was developed is limited to USACE's role in ensuring energy efficiency during the construction of new facilities.

After drafting a definition, USA-CERL worked with USACE to arrive at the following statement:

Acceptance testing of HVAC systems is a systematic procedure to be used by USACE representatives and inspectors to evaluate HVAC components of new construction projects. The procedure will ensure that design and installation are in accordance with accepted minimum energy efficiency standards and specifications.

Development of acceptance tests must consider the time required to perform them, level of personnel training, and cost of instrumentation. In addition, all components of the HVAC system will have to be considered. The varying levels of difficulty of performing acceptance tests on different components also must be examined.

In view of the great variety of systems available, the number of components can become very large. Therefore, a checklist of every item to be examined should first be compiled for possible inclusion in the procedure. From this list, inapplicable items can be deleted later.

USA-CERL has completed proposed checklists for the refrigeration process (evaporators, compressors, condensers, chillers), pumps, piping systems, boilers, and terminal units. These checklists were formulated by first interviewing professional mechanical engineers, who were asked how they ensure that systems are designed and installed correctly and that operating efficiencies are maximized. Mechanical contractors were then interviewed to learn about the conventional installation process for HVAC systems. Design manuals, manufacturers' data, testing and balancing handbooks, and textbooks were researched to obtain in-depth information on the different types of systems. All information was compiled into the checklists.

Development of all required checklists was completed in early FY87; USA-CERL is currently developing acceptance testing procedures. The checklists completed so far comprise Appendix C. During research to compile the checklists, information also was gathered on methods for improving the efficiency of existing systems. Since installation O&M personnel may find this information beneficial, it has been included as Appendix D.

5 CONCLUSIONS AND RECOMMENDATIONS

Efforts are continually underway in USACE to improve the quality of military construction. An area where existing guidance is extremely limited is in the acceptance testing of newly installed HVAC systems. The only current guidance for field inspectors is that listed in the construction specifications; however, these specifications usually do not provide inspectors with information needed to determine if a system is operating at its highest efficiency. Moreover, the TAB reports produced by the contractor often are not adequate verification that an installed system is indeed performing as designed or intended. The integrity of the test reports is sometimes doubtful and results cannot be relied upon as proof that the system has been balanced correctly.

To implement overall improvements in the MCA procedure and ensure energy-efficient facilities, the following steps are recommended:

1. A system for rapidly identifying and accessing energy-related specifications on high-density media should be developed for use by designers and field inspection personnel.
2. USACE should continue to improve the CQC/QA inspection process. HVAC system expertise among USACE field personnel can be further improved through training.
3. The bid process should be tightened to prevent unqualified contractors from bidding on projects they are incapable of completing.
4. USACE should continue to improve the CQC/QA inspection process. Expertise among USACE personnel can be improved through training.
5. All new facilities should have a system-wide operating manual supplied by the contractor--not just a set of operating instructions for some components.
6. A regular training program should be established for installation maintenance personnel to explain the HVAC system in its entirety.
7. A reliable acceptance testing procedure should be developed for USACE inspectors to use in verifying that newly installed HVAC systems are operating as designed and at maximum efficiency. USA-CERL should continue working toward this objective by expanding the procedures developed so far.

APPENDIX A:

FIELD OPERATING AGENCIES CONTACTED IN SURVEY

Districts (Construction Branch)

Louisville, KY

Savannah, GA

Norfolk, VA

Fort Worth, TX

Omaha, NE

Seattle, WA

Area/Resident Offices

Vandenberg AFB, CA

Fort Gordon, GA

Fort Stewart, GA

Fort Riley, KS

Fort Campbell, KY

Fort Bragg, NC

Wright-Patterson AFB, OH

Fort Jackson, SC

Fort Bliss, TX

Fort Hood, TX

Fort Lee, VA

Fort Lewis, WA

DEH

Fort Carson, CO

Fort Bliss, TX

Fort Hood, TX

APPENDIX B:

INSTRUMENTS PROPOSED FOR USE BY FIELD OFFICES IN TESTING, ADJUSTING, AND BALANCING INSPECTIONS

The instruments listed in this appendix should be available to USACE inspectors for verifying the contractor's TAB work. Because of the instruments' delicacy, they should be calibrated at regular intervals as recommended by the manufacturers.

1. Airflow instruments:

a. Manometer, inclined/vertical - used for airflow pressure readings and usually constructed from a solid transparent block of plastic. It has an inclined scale that gives accurate air pressure readings from 0 to 1.0 in. water gauge and a vertical scale for reading greater pressures.

b. Pitot tube - used in conjunction with a suitable manometer to provide a simple method of determining the air velocity in a duct. The pitot tube is used for measuring airstream "total pressure" by connecting the inner tube outlet connector to one side of a manometer. It also can measure airstream "static pressure" by connecting the outer tube side outlet connector to one side of a manometer and "velocity pressure" by connecting to opposite sides of a manometer or draft gauge.

c. Pressure gauge (magnehelic) - an easy-to-use pressure gauge for air system work with many different pressure ranges--from 0 to 0.25 in. water gauge, up to 150 in. water gauge. The "high" pressure connection is used (relative to the atmosphere) for reading positive pressures and the "low" pressure connection is used for negative pressures. By using both, it is possible to measure a pressure drop or rise across components in HVAC systems.

d. Anemometer, rotating vane - consists of a lightweight, wind-driven wheel connected through a gear train to a set of recording dials that read linear feet of air passing through the wheel over a measured length of time. The instrument reads in feet and a timing instrument determines velocity.

e. Flow-measuring hood - used to cover the terminal device to facilitate taking air velocity or airflow readings. The conical or pyramid-shaped hood can be used to collect all air discharged from an air terminal and guide it over flow-measuring instrumentation.

f. Smoke devices - used to study airflow and detect leaks.

1. Smoke bombs - available in various sizes with different lengths of burning time from which highly visible, nontoxic smoke readily mixes with air, simplifying the observation of flow patterns.

2. Smoke sticks and candles - provide a stream of smoke as an indicator; available in different sizes for convenience. Some are like the puff from a cigarette and others smoke continuously for a few minutes to a maximum of 10 min.

3. Smoke guns - used to trace air currents, to determine the direction and velocity of airflow, and to determine the general behavior of either warm or cold air in rooms.

2. Hydronic instruments:

a. Manometer U-tube - used to measure partial vacuum and pressure, both for air and hydronic systems. Recommended for pressure drops above 1 in. water gauge across filters, coils, fans, terminal devices, and sections of ductwork; not recommended for readings of less than 1.0 in. water gauge.

b. Pressure gauge, calibrated - used primarily for checking pump pressures, coil, chiller, and condenser pressure drops, and pressure drops across orifice plates, venturis, and other flow-calibrated devices.

c. Pressure gauge, differential - used when two pressure measurements, one on the high-pressure side and one on the low-pressure side, are taken. The differential pressure, or pressure drop, is then the difference between the two pressure readings.

d. Pressure readout meters - used to measure pressure differentials across circuit setters. Using the pressure differential, the gallons per minute (gpm) can be determined from charts.

3. Rotation instruments:

a. Tachometer, centrifugal - used to measure the revolutions per minute (rpms) with no timepiece required.

b. Tachometer, electronic (stroboscope) - an electronic tachometer that uses an electronically controlled, adjustable flashed light. When the frequency of the flashing light is adjusted to equal that of the rotating machine, the machine will appear to stand still.

4. Temperature instruments:

a. Thermometer, dial-type - used to measure temperature. Dial-type thermometers are rugged, easy to read, and fairly inexpensive. They are available in two general types: stem and flexible capillary.

b. Thermometer, digital (electric) type - used to measure temperature. Digital thermometers are sold in a case containing items such as batteries, switches, knobs to adjust variable resistances, and a sensitive meter. Temperature-sensing elements are remote from the instrument case and connected to it with wire. Advantages of electric thermometers are: remote reading, good precision, flexible temperature range, and ability to use a number of temperature sensors.

c. Psychrometer - the sling psychrometer consists of two mercury-filled thermometers, one of which has a cloth wick or sock around its bulb. Both are mounted side-by-side on a frame fitted with a handle by which the device can be whirled with a steady motion through the surrounding air. Due to evaporation, the wet bulb thermometer will indicate a lower temperature than the dry bulb thermometer. The difference between the two readings is known as the wet bulb depression.

5. Electrical instrument: volt-ammeter - used to measure voltages and electrical currents. The unit of measure for voltage is volts and that for current is amperes.

APPENDIX C:

HVAC CHECKLISTS FOR ACCEPTANCE TESTING

Refrigeration

Basic Principles

The compressor raises the pressure of refrigerant vapor so that the vapor's saturation temperature is slightly above the temperature of a cooling medium—for example, air or water. This difference in temperature allows transfer of heat from the vapor to the cooling medium so that the vapor can condense. The liquid next expands to a pressure such that its saturation temperature is slightly below the temperature of the product to be cooled. This difference in temperature allows heat transfer from the product to the refrigerant, causing the refrigerant to evaporate. The vapor formed must be removed by the compressor at a rate fast enough to maintain the low pressure in the evaporator and to keep the cycle operating.

Classifications

1. Closed system - refrigerant fluid is confined within the system and recirculates through the processes in the cycle.
2. Open system - fluid used as the refrigerant can pass through the system once and then be disposed of or stored in a holding tank for reuse.
3. Simple cycles - employs one set of components and a single refrigeration cycle.
4. Compound cycles - achieves temperatures of approximately 100°F by using two or three compressors in series and a common refrigerant. This keeps the individual machines within their application limits. A refrigerant gas cooler normally is used between compressors to keep the final discharge temperature at a satisfactory level.
5. Cascade cycles - consist of two or more separate refrigerant cycles. The cascade condenser evaporator rejects heat of the high-temperature cycle to the evaporator, which condenses the refrigerant of the low-temperature cycle.

Parts of a Refrigeration System

| | |
|--|-----|
| 1. Evaporator | [] |
| 2. Thermal expansion valve | [] |
| 3. Capillary tube | [] |
| 4. Float valve | [] |
| 5. Pressure-controlled expansion valve | [] |
| 6. Suction piping | [] |
| 7. Evaporator (suction) pressure regulator | [] |
| 8. Suction line filter | [] |
| 9. Suction stop valve | [] |
| 10. Compressor | [] |
| 11. Discharge stop valves | [] |
| 12. Hot gas piping | [] |
| 13. Condensers | [] |
| 14. Receiver | [] |
| 15. Head pressure regulator | [] |
| 16. Refrigerant charging connection | [] |
| 17. Filter drier | [] |
| 18. Liquid solenoid | [] |
| 19. Liquid sight glass | [] |
| 20. Hot gas bypass and valve | [] |
| 21. Relief devices | [] |
| 22. Refrigerant charge | [] |
| 23. Compressor muffler | [] |
| 24. Compressor flexible connections | [] |
| 25. Safety controls | [] |
| 26. Operation controls | [] |
| 27. Chillers | [] |

Evaporator

Evaporator - the heat exchanger in which the medium being cooled, usually air or water, gives up heat to the refrigerant through the exchanger transfer surface. Liquid refrigerant boils to become a gas in the process of the heat absorption.

SECTION I

Check the following for evaporator classification:

1. Direct expansion - usually installed directly in the airstream ductwork; has a shell and tube type structure. Evaporating refrigerant is inside the tubes whereas the cooled liquid is in the shell side []
2. Flooded shell-and-tube - refrigerant vaporizes on the outside of bare augmented surface tubes which are submerged in evaporating liquid refrigerant within a closed shell. Cooled liquid flows through these tubes, which may be straight, U-shaped, or coiled []
3. Spray cooler - similar to a flooded shell-and-tube cooler except that refrigerant liquid is recirculated through the spray nozzles located above the top tubes []
4. Dry expansion cooler - refrigerant is in the tubes and the liquid to be chilled is in the shell []
5. Bandelot - used in industrial applications for cooling a liquid to a point near freezing. Liquid is circulated over the outside of several horizontal tubes, one above the other. Liquid is distributed uniformly along the length of the top tube and flows by gravity to the tubes below []
6. Double tube - consists of a tube within a tube. Refrigerant may be circulated in either the inner tube or the annular space between tubes. Generally, water or brine is circulated through the inner tube due to ease of maintenance []

SECTION II

Evaporator selection parameters:

1. Evaporator pressure []
2. Evaporator temperature []
3. Water pressure change []
4. Entering water/air temperature []
5. Leaving water/air temperature []
6. Water/air temperature change []
7. Gallons/minute (gpm) []
8. Air cubic feet/minute (cfm) []

SECTION III

Do the following steps before starting up the system:

1. Confirm that evaporator piping has provisions for measuring pressure, temperature, and flow []
2. Ensure that evaporator piping is correctly sized to handle the flow that will be needed for the required heat transfer []
3. Check cooling water pump's water level and makeup water valve []
4. Confirm that provisions have been made for evaporator water bleed-off and chemical treatment []
5. Check for obstructions that can cause short-circuiting of airflow into or away from the evaporator []
6. Check the spray nozzles' pattern and confirm that all are working []
7. Verify that all control dampers of head pressure controls are working properly []
8. Verify nameplate data and add any missing information: []
 - a. Make/model no. []
 - b. Type/size []
 - c. Serial no. []
 - d. Gallons/minute (gpm) []

Compressor

Compressor - pump in a refrigeration system which compresses refrigerant vapor into a smaller volume, thereby raising the pressure of the refrigerant and consequently its boiling temperature. The compressor separates low and high pressure sides.

General note: the compressor should be located in a clean, dry, well-ventilated space. Adequate space should be left around and over the compressor for servicing; it should be accessible from all sides. The top of the compressor should be left above the unit for removing evaporators and other items. The compressor should be at least 12 inches from the crankshaft.

SECTION I

Check the following list for compressor classification:

1. Reciprocating compressors - most are single-acting and use crank type pistons that are driven directly through a pin and connecting rod from the crankshaft.
 - a. Single stage compressors []
 - b. Booster compressors - the booster raises the refrigerant pressure to the level at which further compression can be achieved using a high stage compressor without exceeding the compression ratio limitations of the respective machines []
 - c. Two stage compressors - provide a way to achieve low temperatures (-80°F using Refrigerant 22) within the frame of a single compressor []
 - d. Open type compressors - shaft extends through the seal in the crankcase for an external drive []
 - e. Hermetic compressors - the motor and compressor are contained within the same pressure vessel; the motor shaft is integral with the compressor crankshaft and the motor is in contact with the refrigerant []
 - f. Semihermetic - bolted construction, amenable to field repair []
 - g. Welded shell hermetic compressor - the motor is mounted inside a steel shell which, in turn, is sealed by welding []
2. Rotary compressors - have circular, or rotary, motion instead of reciprocating motion. Their positive displacement compression process is nonreversing and is either continuous or cyclical, depending on the mechanism used. Most are direct drive.
 - a. Rolling piston type - uses a roller mounted on an eccentric shaft with a single vane or blade suitably positioned on the nonrotating cylindrical housing; has a provision for this blade to reciprocate with the eccentrically moving roller []

- b. Rotating vane type - has a rotor concentric with the shaft; vanes are in the rotor. This assembly is off center with respect to the cylindrical housing []
- 3. Helical rotary compressors (screw compressors) - positive-displacement type.
 - a. Single screw compressors - consist of a single main rotor cylindrical in shape, working with a pair of star wheels (or gate rotors) []
 - b. Twin screw compressors - consist of two mating, helically grooved rotors, a male (lobes) and a female (gullies) in a stationary housing with inlet and outlet gas ports. Gas flow in the rotors is both radial and axial []
- 4. Centrifugal compressors (turbocompressors) - characterized by a continuous exchange of angular momentum between a rotating mechanical element and a steadily flowing fluid.
 - a. Open-type - shaft extends through the seal in the crankcase for an external drive []
 - b. Hermetic compressors - the motor and compressor are contained within the same pressure vessel; the motor shaft is integral with the compressor crankshaft and the motor is in contact with the refrigerant []

SECTION II

Compressor selection parameters:

- 1. All compressors:
 - a. Capacity - amount of heat to be exchanged by the refrigeration system in the evaporator []
 - b. Evaporator temperature - refrigeration temperature required to absorb heat from the medium being cooled []
 - c. Condensing temperature - refrigerant temperature required to reject heat to the condensing medium []
 - d. Refrigerant - four main refrigerants used in reciprocating compressors are refrigerants (R-) 12, 22, 500, and 502 []
 - e. Subcooling of the condensed refrigerant - subcooling increases the potential refrigeration effect by reducing the percentage of liquid flashed during expansion []

- f. Superheating of the suction gas - superheating can occur by heat pickup in piping outside the cooled space, in a liquid suction heat exchange, or in an evaporator within the cooled space []
- g. Refrigerant line pressure drops []
- h. Operating limits:
 - (1) Saturated suction temperature to a maximum of 50°F []
 - (2) Compression ratio []
 - (3) Discharge temperature at the discharge valve []
- i. Heat rejection []
- 2. Centrifugal compressors:
 - a. Load []
 - b. Chilled water or brine quantity []
 - c. Temperature of chilled water or brine []
 - d. Condensing medium to be used []
 - e. Quantity of condensing medium and temperature []
 - f. Type and quantity of power available []
 - g. Fouling factor allowance []
 - h. Amount of usable space available []
 - i. Nature of the load []
 - j. Is the load variable or constant? []
- 3. Compressor protection devices:
 - a. Motor protection:
 - (1) Current sensitive overloads []
 - (2) Temperature sensing devices []

b. Protection devices:

(1) High-pressure protection:

- (a) High-pressure cutout _____ []
- (b) High-to-low side internal relief valve or rupture member
_____ []
- (c) Relief valve or rupture member on the compressor casing
similar to those used on other pressure vessels _____ []

(2) High-temperature control devices to protect against overheating
and oil breakdown:

- (a) Motor temperature devices _____ []
- (b) Limit switch - stops compressor when discharge temper-
atures exceed safe values to protect against oil and
refrigerant breakdown _____ []
- (c) Thermostat - limits maximum oil temperature; used where
crankcase heaters are installed to maintain a minimum
crankcase temperature _____ []

(3) Low-pressure protection:

- (a) Protective switch provided to control minimum suction
pressure _____ []
- (b) Oil pressure protectors with forced-feed lubrication
systems to prevent the compressor from operating at too
low a pressure _____ []
- (4) Time delay or lockouts with manual resets to prevent damage
to both compressor and contactors due to repetitive rapid
cycling _____ []
- (5) Low-voltage or burnout protection guards to protect against
slow changes in voltage which can lead to excessive currents
or motor heating; single phasing or phase loss protection
_____ []

4. Reciprocating compressors only:

- a. Crankcase _____ []
- b. Crankshaft _____ []
- c. Main bearing _____ []
- d. Connecting rods and eccentric straps _____ []
- e. Piston, piston ring, and piston pin _____ []

f. Suction and discharge valves _____ []

g. Lubrication:

(1) Simple splash system - low to medium bearing loads _____ []

(2) Flooded systems _____ []

(3) Forced-feed systems - develop pressure using a pump _____ []

h. Stationary seals - more expensive, used on open-type reciprocating compressors _____ []

5. Rotary compressors only:

a. Shafts _____ []

b. Journals and bearings _____ []

c. Blades _____ []

d. Valves _____ []

e. Lubrication _____ []

Condensers

Condenser - the heat exchanger in which heat absorbed by the evaporator and some of the heat of compression introduced by the compressor are removed from the system. The gaseous refrigerant also changes into a liquid here.

SECTION I

Check for condenser classification by cooling medium:

1. Water-cooled condensers - an advantage of this type is that, where plenty of low-cost water is available, both first cost and operating costs may be lower than with other condensers. Disadvantages are that (1) where cooling towers are used to produce cooling water, the initial cost may be higher and (2) the lower operating cost of the water-cooled system may be offset by cooling tower pump and fan power maintenance costs.
 - a. Shell-and-tube (horizontal, 4.3 tons and up) - refrigerant condenses on the shell side and cooling water is circulated through the tubes in a closed, single, or multipass circuit
[]
 - b. Shell-and-tube (vertical) - features an open water circuit; commonly used in ammonia refrigeration systems. Advantages are:
 - Large condenser capacity may be installed in small floor space.
 - Complete installation costs are low.
 - Water distribution is simplified.
 - Large space is available in the condenser for storing liquid ammonia.
 - Adaptable to easy purging of contaminant.
 - Tubes are easily cleaned without shutting down the system.
 - Can be made to carry large overloads by increasing the quantity of water circulated through the tubes while, at the same time, avoiding a heavy increase in friction head.
 - Can be used effectively with condensing water from a cooling tower or spray pond.
 - c. Shell-and-U tube condenser - similar to a shell-and-tube condenser, except that cooling water in the former is circulated through a bundle of U-tubes terminating in a single tube sheet
[]
 - d. Double pipe or tube in tube condenser - consists of one or more assemblies of two tubes, one within the other, in which the refrigerant vapor is condensed in either the annular space or the inner tube
[]

e. Atmospheric condenser - consists of a number of horizontal tubes arranged one above the other. Refrigerant condenses within the tubes and the cooling water is distributed along the top tube, flowing by gravity over the tubes directly below. Enough water must be circulated to obtain uniform, complete wetting of the tubes _____

[]

2. Air-cooled condensers - (three processes--desuperheating, condensing, and subcooling). Advantages are:

- If air is readily available, disposal is no problem.
- First cost is lower than for other condensers that involve water.
- Maintenance costs are low.

Disadvantages are:

- Large volumes of air are required, which may produce noise.
- Operating costs are high because, at full load, the power drive to the compressor is high.
- Capacity increases when the system load declines, creating operating problems at partial loads.
- If the outdoor temperature is low, start-up can be difficult.
- As a general rule for air-cooled operation, a 20 percent larger compressor is required.

a. Condenser remote from the compressor (used for refrigeration systems from 1/2 ton to over 500 tons) - forced air is the most common type _____

[]

b. Condenser as part of a condensing unit - basic design considerations are the same as those for remote condensers, but inclusion of the compressor makes it desirable in most cases to enclose the components in a cabinet. This cabinet also contains controls, pre-charged line fittings or valves, and liquid receivers that are separate from the coil _____

[]

3. Evaporative condensers - reject heat from a condensing vapor into the environment _____

[]

SECTION II

Condensing unit selection parameters:

1. Water-cooled:

- a. Condenser water source _____ ☐
- b. Fouling factor _____ ☐
- c. Entering condenser water temperature _____ ☐
- d. Water quantity _____ ☐
- e. Finned tubes _____ ☐
- f. Fixed tube sheets _____ ☐
- g. Cooling towers _____ ☐
- h. Spray ponds _____ ☐
- i. Pump power _____ ☐
- j. Tower fans _____ ☐
- k. Control valves _____ ☐
- l. Chemical treatment _____ ☐

2. Air-cooled condensers:

- a. Finned condenser coil _____ ☐
- b. One or more fans and motors _____ ☐
- c. Enclosure or frame _____ ☐
- d. Controls _____ ☐
- e. Precharged line fittings or valves _____ ☐
- f. Liquid receiver (if separate from coil) _____ ☐
- g. Entering air temperature _____ ☐
- h. Air flow _____ ☐

3. Evaporative condensers:

- a. Saturated condensing temperature ☐
- b. Entering air wet bulb temperature ☐
- c. System refrigeration capacity ☐
- d. Total wattage input ☐
- e. Compressor brake horsepower ☐
- f. Condensing coil ☐
- g. Fan(s) ☐
- h. Spray water pump ☐
- i. Water distribution system ☐
- j. Cold water pump ☐
- k. Drift eliminators ☐
- l. Water make-up assembly ☐
- m. Chemical treatment ☐

SECTION III

Do the following steps before starting up the system:

- 1. Confirm that condenser piping has provisions for measuring pressure, temperature, and flow ☐
- 2. Ensure that condenser piping can handle the flow that will be needed for the required heat transfer ☐
- 3. Check cooling water sump water level and makeup water valve ☐
- 4. Confirm that provisions have been made for condenser water bleed-off and chemical treatment ☐
- 5. Check for any obstruction that can short-circuit airflow into or away from the condenser ☐
- 6. Check spray nozzles' pattern and confirm that all are working ☐
- 7. Verify that all control dampers of head pressure controls are working properly ☐

8. Verify nameplate data and add any missing information: _____ []
- a. Make/model no. _____ []
- b. Type/size _____ []
- c. Serial no. _____ []
- d. Volts/phase _____ []
- e. cfm _____ []

Liquid Chillers

Chiller - cools water, brine, or other secondary refrigerant liquid for air-conditioning or refrigeration.

SECTION I

Check for chiller classification:

1. Chiller type:

- a. Reciprocating liquid chillers (up to 200 tons) _____ []
- b. Centrifugal liquid chillers (80 tons to more than 800 tons) _____ []
- c. Screw liquid chillers (120 tons to 800 tons) _____ []

2. Chiller system:

- a. Hermetic - employs a hermetic compressor with an electric motor totally enclosed in a refrigerant atmosphere _____ []
- b. External drive - uses a compressor that can be driven by a turbine, engine, or external electric motor _____ []
- c. Multiple chiller system - offers standby capacity in case repair work must be done on one chilling machine
 - (1) Parallel - liquid to be chilled is divided among the liquid chillers; the multiple chilled streams are combined again in a common line after chilling. As the cooling load decreases, one unit may be shut down, but the remaining units must then provide liquid chilled colder than the design temperature so that when all streams combine (including ones from the idle machines) design chilled liquid supply temperature is provided in the common line _____ []
 - (2) Series - the series arrangement is better in most respects, except that chilled liquid pressure drop may be higher if shells with fewer liquid-side passes or baffles are not available. Over-chilling by either unit is never required, and compressor power consumption is lower than that for parallel arrangement at partial loads _____ []

SECTION II

Chiller selection parameters:

1. Cooling capacity (tons of refrigeration) _____ []
2. Chilled water temperature (leaving chiller) _____ []
3. Temperature of water entering chiller _____ []
4. Amount of chilled water to be circulated (gpm) _____ []
5. Condensing temperature _____ []
6. Important components:
 - a. Thermal expansion valve - used at low capacities with reciprocating and centrifugal chillers _____ []
 - b. High-pressure float - controls liquid refrigerant flow to the cooler _____ []
 - c. Relief valves (or rupture disks) - set to relieve at the shell design working pressure; must be provided on all pressure vessels. Connected to the high or low side. Fusible plugs also may be used in some locations. These devices should be vented outdoors _____ []

Pumps

Pump - device used to produce water flow in piping.

SECTION I

Check for pump classification:

1. Pump type:

- a. Centrifugal _____ ☐
- b. Rotary _____ ☐
- c. Reciprocating _____ ☐

2. Impeller type:

- a. Single suction (one intake) _____ ☐
- b. Double suction (two intakes) _____ ☐
- c. Multistage pumps (multiple impellers) _____ ☐

3. Casing type:

- a. *Volute* (discharge perpendicular to shaft) _____ ☐
- b. Diffuser (discharge parallel to shaft) _____ ☐

4. Method of connection to driver:

- a. Close-coupled (impeller mounted on motor shaft extension) _____ ☐
- b. Flexible-coupled (impeller shaft supported by frame or bracket; connected to the electric motor through a flexible coupling) _____ ☐

5. Mounting position:

- a. Horizontal _____ ☐
- b. Vertical _____ ☐
- c. Base-mounted _____ ☐
- d. Suspended wet pit _____ ☐
- e. Frame-mounted _____ ☐

SECTION II

Pump selection parameters for all pumps:

1. Materials:

- a. Bronze-fitted _____ ☐
- b. All bronze _____ ☐
- c. Iron-fitted _____ ☐

2. Stuffing box:

- a. Mechanical seal (to avoid undesirable leakage) _____ ☐
 - (1) Unbalanced (higher pressure seals) _____ ☐
 - (2) Balanced (lower pressure seals) _____ ☐
 - (3) Inside (rotating element inside) _____ ☐
 - (4) Outside (rotating element outside) _____ ☐

3. Packing _____ ☐

4. Shaft sleeves (protect motor or pump shaft) _____ ☐

5. Wearing rings (protect motor or pump shaft) _____ ☐

6. Ball bearings (used where motor and pump bearings are sleeve-type) _____ ☐

7. Balance ring (used on single-inlet, enclosed impeller to reduce axial load) _____ ☐

8. Rotation is determined by:

- a. Type of vanes _____ ☐
- b. Suction connections _____ ☐
- c. Discharge connections _____ ☐

Note: pumps with a "mechanical seal" must not be run dry, even when "bumped" to determine rotation.

9. Drives:

- a. Motor-driven _____ ☐
- b. Belt-driven (usually pump fuel oil) _____ ☐

10. Operating speeds (rpm) _____ ☐

11. Type of service:

- a. Continuous _____ []
- b. Intermittent _____ []

12. Current characteristics:

- a. Voltage _____ []
- b. Cycles _____ []
- c. Phase _____ []

13. Water temperature _____ []

SECTION III

Do the following steps before starting up the pump system:

1. Confirm that all pumps have been cleaned and checked, and verify that all bearings have been lubricated, rotation is free and correct, motors and drivers have been aligned and fastened securely, and pump bases have been grouted correctly _____ []
2. Confirm that access has been provided for pressure and/or temperature readings _____ []
3. Locate all start/stop, disconnect switches, electrical interlocks, and motor starters _____ []
4. Verify the compatibility of voltage and phase _____ []
5. Verify that all strainers are clean _____ []
6. Check system temperature and pressure combinations as well as piping connections at pump inlets for possible flashing or cavitation problems _____ []
7. Verify pump name plate data and add any missing information:
- a. Manufacturer _____ []
- b. Serial no. _____ []
- c. Model no. _____ []
- d. Size _____ []
- e. Impeller size _____ []
- f. Design head _____ []
- g. Design flow _____ []
- h. Other _____ []

Piping Systems

SECTION I

Check for piping system classification:

1. One-pipe system. Advantages are:

- Low installation cost. Often needs only short mains or no mains.
- Works well in single-story buildings.

Disadvantages are:

- Water temperature drops progressively as each radiator transfers heat to the air, making it harder to control the temperature.
- Individual radiators cannot be shut off.

2. Two pipe reversed return. Advantages are:

- Generally is self-balancing.
- Helps keep pipes the same size.
- Water flow distance to and from the boiler is virtually the same through any unit.

3. Two-pipe direct return. An advantage is that it requires less distribution main piping. Disadvantages are:

- Circuit balancing usually is required.
- Operating costs usually are higher because of pumping required to offset pressure losses due to added balancing fittings.

SECTION II

Piping selection parameters:

1. Connections _____ []
2. Fittings:
 - a. Pipe flanges _____ []
 - b. Unions _____ []
 - c. Strainers _____ []
 - d. Anchors _____ []
 - e. Eccentric reducers _____ []
 - f. Expansion joints _____ []
 - g. Thermostats _____ []
 - h. Hangers or supports _____ []
 - i. Reducers _____ []
3. Traps:
 - a. Float traps _____ []
 - b. Float and thermostatic traps _____ []
 - c. Thermostatic traps _____ []
 - d. Bucket traps _____ []
4. Valves:
 - a. Angle valves _____ []
 - b. Check valves _____ []
 - c. Diaphragm valves _____ []
 - d. Gate valves _____ []
 - e. Globe valves _____ []
 - f. Lock-and shield valves _____ []
 - g. Motor operated valves _____ []
 - h. Pressure reducing valves _____ []
 - i. Relief valves _____ []

SECTION IV

Do the following steps before starting up the system:

1. Confirm that the system is free of leaks and that it has been hydrostatically tested, filled, flushed, refilled, and vented as required by the installing contractor []
2. Confirm that all strainers have been cleaned []
3. Inspect pressure-reducing valve operation and settings for both system valves and makeup water valves []
4. Verify valve settings and locations of all safety and relief valves []
5. Confirm that all manual and automatic valves are in the open position []
6. Inspect and verify that the water level in the expansion tank is correct []
7. Confirm accessibility into ceilings and walls for adjustment of balancing valves for flow meters and for measurement points []
8. Confirm that provisions have been made to obtain temperature, pressure and flow measurements []

Boilers

Boiler - a fuel-burning pressure vessel designed to transfer heat to a fluid.

SECTION I

Check for boiler classification:

1. Boiler type:

- a. Hot water ☐
- b. Steam ☐

2. Working temperature/pressure:

- a. Low pressure ☐
- b. Medium pressure ☐
- c. High pressure ☐

3. Fuel used:

- a. Natural gas ☐
- b. Fuel oil ☐
- c. Propane ☐

Note: all fuels above apply to cast iron and steel boilers.

- d. Electric ☐

4. Construction materials:

a. Cast iron:

- (1) Dry base (fire box beneath the fluid) ☐
- (2) Wet leg (fire box's top and sides enclosed by fluid) ☐
- (3) Wet base (fire box surrounded by fluid, except for necessary openings) ☐

b. Steel:

- (1) Fire tube (fire passes through tubes that are surrounded by liquid) ☐
- (2) Water tube (liquid flows through tubes that are surrounded by fire) ☐

SECTION II

Boiler selection parameters for all boilers:

1. ASME (or other) code section under which the boiler is constructed and tested _____ {}
2. Net boiler output capacity, Btuh (kW) _____ {}
3. Total heat transfer surface, sq ft _____ {}
4. Water content, lb _____ {}
5. Auxiliary power requirements, kWh _____ {}
6. Internal water-flow patterns _____ {}
7. Cleaning provisions for all heat-transfer surfaces _____ {}
8. Efficiency guarantee _____ {}
9. Space requirements and piping arrangements _____ {}
10. Water treatment requirements _____ {}
11. Water column _____ {}
12. Feedwater pump control _____ {}
13. Low water cutoff _____ {}
14. Pressure gauge _____ {}
15. Temperature gauge _____ {}
16. Test connections _____ {}
17. Relief valve _____ {}
18. Forced-draft blower _____ {}
19. Burner flame failure controller _____ {}
20. Control panel _____ {}
21. Dip tube _____ {}

SECTION III

Do the following steps before starting up the boiler:

1. Verify that boiler equipment has been lubricated, started, and tested for proper and safe operation in accordance with the manufacturer's instructions, and that all safety and operating controls have been tested, adjusted, and set for proper operation _____ []
2. Locate all combustion-air openings and barometric or draft control dampers for the boilers and confirm that they are of proper size for the fuel being used _____ []
3. Verify settings and types of all operational and safety control devices, both for temperature and pressure _____ []
4. Check for proper location of air vents, air elimination fittings, and expansion tanks, and that piping to them is correct _____ []
5. Verify that the boilers have been properly flushed and/or blown down _____ []
6. Verify boiler nameplate data and add any missing information _____ []
7. Load types:
 - a. Instantaneous full load considerations. (When the boiler is at maximum load conditions, approximately 5 percent of the time) _____ []
 - b. Partial load considerations. (Because the boiler operates at full load conditions only about 5 percent of the time, it may be adjusted for the most common operating conditions. This adjustment increases efficiency in fuel usage) _____ []

Terminal Units

SECTION I

Check for terminal unit classification:

1. Natural convection units (used in heating only):

- a. Cast-iron radiators _____ []
- b. Cabinet convectors _____ []
- c. Baseboard and finned tube radiation _____ []

2. Forced convection units:

- a. Unit heaters _____ []
- b. Unit ventilators _____ []
- c. Fan-coil units _____ []
- d. Induction units _____ []
- e. Air-handling units _____ []
- f. Heating and cooling coils in central station units _____ []
- g. Process heat exchangers _____ []

Note: fan-coil units, unit ventilators, and central station units can be used for heating, ventilating, and cooling.

3. Radiation (generally used in low-temperature water systems):

- a. Panel systems _____ []
- b. Unit radiant panels _____ []
- c. Cast-iron radiators _____ []

Note: cast-iron radiators should not be installed in the same controlled circuit as baseboard or convector units. Caution should also be used when including fan-operated units with natural convection units on the same piping circuit.

4. Filter type and characteristics:

- a. Type and size _____ []
- b. Number _____ []
- c. Cleanliness _____ []
- d. Frame leakage _____ []

5. Fan type and characteristics:

- a. Rotation _____ ☐
- b. Wheel clearance and balance _____ ☐
- c. Bearing and motor lubrication _____ ☐
- d. Drive alignment _____ ☐
- e. Belt tension _____ ☐
- f. Drive set screws tight _____ ☐
- g. Belt guard in place _____ ☐
- h. Flexible duct connector alignment _____ ☐
- i. Starters and disconnect switches _____ ☐
- j. Electrical service and connections _____ ☐

6. Mounting:

- a. Floor-mounted _____ ☐
- b. Wall-mounted _____ ☐
- c. Recessed _____ ☐
- d. Ceiling-hung _____ ☐

7. Enclosure:

- a. Louvers _____ ☐
- b. Penthouse _____ ☐
- c. Gooseneck _____ ☐
- d. Other _____ ☐

8. Damper type and characteristics:

- a. Quality _____ ☐
- b. Location _____ ☐
- c. Fresh air _____ ☐
- d. Return air _____ ☐
- e. Discharge _____ ☐

f. Control method:

(1) Manual _____ []

(2) Automatic _____ []

9. Heating coil type and characteristics:

a. Aluminum _____ []

b. Copper _____ []

c. Number of rows _____ []

d. Row arrangement _____ []

e. Fin spacing and condition _____ []

f. Obstructions and/or debris _____ []

g. Airflow and direction _____ []

h. Piping leakage _____ []

i. Correct piping connections _____ []

j. Valves open or set _____ []

k. Air vents or steam traps _____ []

SECTION III

Check the following items and provide necessary data to help in the selection of terminal units:

1. CFM: (design) _____ cfm to _____ total cfm _____ []
(actual) _____ cfm to _____ total cfm _____ []

2. GPM: (design) _____ GPM to _____ total GPM _____ []
(actual) _____ GPM to _____ total GPM _____ []

3. BTU: (design) _____ Btuh _____ []
(actual) _____ Btuh _____ []

4. Lb of steam _____ []

5. Motor horsepower _____ []

6. Out-air temperature: (design) _____ degrees F _____ []
(actual) _____ degrees F _____ []

7. Water supply temperature: (design) _____ degrees F _____ []
(actual) _____ degrees F _____ []

8. Remarks _____ []

SECTION IV

Do the following steps before starting up the system components:

1. Louvers installed _____ ☐
2. Manual dampers open and locked _____ ☐
3. Automatic dampers set properly _____ ☐
4. Housing construction leakage _____ ☐
5. Access door leakage _____ ☐
6. Condensate drain piping and pan _____ ☐
7. Free from dirt and debris _____ ☐
8. Verify name plate data:
 - a. Terminal unit:
 - (1) Manufacturer _____ ☐
 - (2) Serial no. _____ ☐
 - (3) Model no. _____ ☐
 - (4) Maximum capacity in _____ ☐
 - (5) Maximum capacity out _____ ☐
 - (6) Other _____ ☐
 - b. Fan:
 - (1) Serial no. _____ ☐
 - (2) Model no. _____ ☐
 - (3) Other _____ ☐

APPENDIX D:

IMPROVEMENTS TO EXISTING BUILDING HVAC SYSTEMS

This appendix contains steps that can be used to increase energy efficiency of HVAC systems at existing buildings.

Evaporator

1. Fouling can be resisted by using copper and other nonferrous tubes rather than steel tubes _____ []
2. Fouling can be reduced by keeping velocities through tubes at 6 to 13 ft/sec _____ []
3. Ensure that the flooded evaporator is not overcharged, causing carryover of liquid refrigerant to the compressor. This can reduce the system's operating efficiency or even damage the compressor _____ []
4. Ensure that the flooded evaporator is not undercharged. This condition can cause poor performance because the uppermost tubes in the evaporator are not in contact with liquid refrigerant and therefore cannot be used for the evaporation process _____ []
5. By applying the "overfeed system" to a direct-expansion evaporator, cooler performance can be improved greatly. This can be done by not completely evaporating the liquid refrigerant in its passage through the cooler and recirculating the remaining liquid by mechanical, jet pumps, or thermosiphon action _____ []
6. When used with reciprocating-compression equipment, it is necessary to ensure adequate oil return from the evaporator _____ []
7. Ensure that flash-gas is introduced properly into the evaporator for satisfactory performance. Improper distribution of this gas can result in liquid carryover to the compressor and damage to the exchanger tubes from erosion or vibration _____ []
8. Check suction gas leaving the evaporator to make sure that it is dry. If not, it can cause compressor damage _____ []

Condensers

1. Water-cooled condensers:

- a. Clean the unit either mechanically with a brush or chemically with a solution _____ []
- b. Immediately repair leaks in one or more tubes that may develop because of the corrosive nature of impurities in the water or through improper cleaning procedures _____ []

2. Air-cooled condensers:

- a. When condensers are located indoors, the warm air discharge must be conducted to the outdoors _____ []
- b. In outdoor installations of vertical face condensers, prevailing winds should blow toward the air intake or discharge shields should be used to deflect opposing winds _____ []
- c. The receiver should be equipped with a purge valve and a sight glass _____ []
- d. Relubrication of fan bearings and fan motors should be scheduled _____ []
- e. Adjustment of belt tension may be necessary after installation and at yearly intervals _____ []
- f. Condenser coil may require periodic cleaning to remove lint or leaves _____ []

3. Evaporative condensers:

- a. Check fan and motor bearings and lubricate if necessary. Check tightness and adjustment of thrust collars on sleeve-bearing units and locking collars on ball-bearing units _____ []
- b. Check belt tension _____ []
- c. Clean strainer. If air is extremely dirty, strainer may need frequent cleaning _____ []
- d. Clean and flush pump _____ []
- e. Check operating water level in sump and adjust makeup valve if required _____ []
- f. Check water distribution, adjust and flush out troughs, and clean spray nozzles if necessary _____ []
- g. Check bleed water line to ensure it is operating and is adequate as recommended by manufacturer _____ []

- h. Check fans and air inlet screens and remove any dirt or debris _____ ☐
- i. Inspect unit carefully for general preservation and cleanliness and make needed repairs _____ ☐
- j. Check operation of controls such as modulating capacity control dampers _____ ☐
- k. Check operation of freeze control items such as pan heaters and their controls _____ ☐
- l. Check water treatment system for proper operation _____ ☐

Compressors

1. A tight system is important. Leaks on compressors operating at sub atmospheric pressures allow noncondensables and moisture to enter the system, adversely affecting system operation and component life. Leakage in higher pressure systems allows oil and refrigerant loss. Vacuum leaks can be detected by a change in operational pressures which is not supported by either the corresponding refrigerant temperature data or the frequency of purge unit operation. Pressure leaks are characterized by symptoms related to refrigerant charge loss such as low suction pressures and high suction superheat. These leaks should be detected and stopped to prevent component deterioration []
2. Compliance with the manufacturer's recommended oil filter inspection and replacement schedule will allow visual indication of the compressor lubrication system's condition. Repetitive clogging of filters can mean system contamination. Periodic oil sample analysis can be used to monitor acid, moisture, and particulate levels to assist in detecting problems []
3. Operating and safety controls should be checked and calibrated periodically to assure system reliability []
4. The electrical resistance of hermetic motor windings between phases and to grounds should be checked on a planned basis, following the manufacturer's outlined procedure. This will help detect any internal electrical insulation deterioration or the formation of electrical leakage paths before a failure occurs []
5. Water-cooled oil coolers should be cleaned systematically on the water side (depending on water conditions) and the operation of any automatic water control valve should be checked []
6. For some compressors, periodic maintenance is required, such as manual lubrication of couplings and other external components and shaft seal replacement. Prime movers and their associated auxiliaries all require routine maintenance. These tasks should be made part of the planned compressor maintenance schedule []
7. The steps necessary in preparing the unit for prolonged shutdown, i.e., winter, and specified instructions for starting up after this standby period should be part of the program. Compressors with internal lubrication systems should have their oil heaters energized continuously throughout this period or should have their oil charges replaced just prior to putting them back into operation []

Chillers

1. Increase evaporator temperature:

- a. Raise supply air temperature []
- b. Raise chilled water temperature []
- c. Operate one of the multiple chillers at full load, rather than two or more at part load []
- d. Maintain a proper refrigerant level []
- e. Keep evaporator heat exchange surfaces clean []
- f. Maintain higher relative humidity levels in air-conditioned space []
- g. Clean all cooling coils, both air and liquid sides []

2. Reduce condensing temperatures:

- a. Clean all condenser - shell and tubes []
- b. Clean all air-cooled condenser coils and fins with compressed air or steam jets on a regular basis []
- c. Remove obstructions to free airflow into cooling tower and fans []
- d. Direct cool exhaust air from the building into the air intake of air-cooled condensers or cooling towers []
- e. Under light loading conditions, i.e., when the refrigeration load is small and the ambient wet bulb temperature is likely to be low, the cooling performance of the tower will exceed the needs of the refrigeration machines. Under these conditions, the cooling tower fan or fans can be cycled on and off to maintain a desired condenser water temperature, thus saving the energy required to drive the fans []
- f. Adjust airflow and water rates to air-cooled condensers and cooling towers to produce the lowest possible condensing temperature. Generally, the savings in refrigeration power will exceed any increase in added power for condenser fans or pumps []
- g. Use well water, if available, for condenser cooling []
- h. Shade cooling towers and air-cooled condensers from direct sunlight []
- i. Remove bacterial slime and algae from cooling towers []

- j. Institute and maintain a continuous water treatment program for cooling towers []
- k. At partial refrigeration loads, operate cooling towers as natural draft towers with cooling tower fans turned off []
- l. Clean and descale spray nozzles []
- m. It is more effective to operate chillers at full load in the morning when outdoor wet bulb temperatures are low and low condensing water temperatures can be obtained from the cooling tower. Therefore, subcool the building during the morning. Then turn the chiller off when wet bulb temperatures rise, and allow the building temperature to drift up. In large buildings, the extensive chilled-water piping system provides a degree of thermal storage []

Boilers:

1. Clean and scrape fire sides to remove soot and scale []
2. Clean water sides to remove built-up scale []
3. Provide and maintain proper insulation on the boiler drum, combustion chamber and burner []
4. Seal any leaks found between sections of cast iron boilers to improve combustion efficiency []
5. Install baffles or turbulators to improve heat transfer if the stack temperature is higher than 450°F []
6. Seal all air leaks into the combustion chamber, especially around doors, frames, and inspection ports []
7. Maintain the lowest possible hot water temperature that will meet space needs []
8. Provide a thermostat to control boiler temperature to 100°F during shutdown []
9. Provide an electronic ignition to save energy during shutdown []
10. If standing pilot lights are used, they should be shut off during non-operating periods []
11. Provide an automatic draft control damper in the breeching or flue pipe to reduce loss during shutdown. An "end switch" should be installed on the flue damper in series with the boiler controls so that the boiler cannot fire until the flue damper is fully open []
12. Verify that a proper refractory is installed in the combustion chamber and in proper working condition before and maintained properly after operation []
13. Ensure that combustion air is provided at a minimum as required by code to reduce unnecessary heat losses []
14. Provide a combustion air fan if necessary for the power burner []
15. Provide a combustion air damper for shutdown periods where local codes allow []
16. In multiple boiler operations, use one boiler at a time to full load before the second boiler is fired to obtain maximum efficiency []
17. Adjust the boiler firing to actual load. This will reduce short-cycling which reduces efficiencies []

18. Adjust burner efficiencies to achieve proper stack temperature and carbon dioxide and excess air settings []
19. Blow down boiler to limit chemical concentration in boiler water and thereby avoid foaming and priming []
20. Provide proper feedwater and boiler water conditioning. This not only influences efficiency, but also increases boiler life and decreases maintenance costs. Objectives for these treatments are to:
 - a. Keep water solids in a form that can be removed by blowdown and thus avoid scale formation []
 - b. Reduce corrosion by avoiding carbon dioxide formation caused by the breakdown of boiler water compounds []
 - c. Control pH and alkalinity, which will keep the boiler metal from becoming brittle and cracking []
 - d. Avoid foaming and priming, which will keep water from carrying over into the steam []
 - e. Eliminate oxygen in the boiler water, which will avoid corrosion []
21. Provide proper fuel conditions:
 - a. Natural gas and propane: provide a proper regulator to obtain the desired inlet operating pressure for the fuel []
 - b. Fuel oil:
 - (1) May require chemical treatment []
 - (2) Will require pumping []
 - (3) May require viscosity control through heating and chemicals, depending on the fuel type []
 - (4) Will require a pressure regulator []

Pumps

Check the following components:

1. Stuffing box glands (free movement) _____ []
2. Gland bolts (clean and oiled) _____ []
3. Packing (remove and check for wear) _____ []
4. Oil-lubricated bearings (drained and filled with fresh oil) _____ []
5. Grease-lubricated bearings (correct amount and consistency of grease) _____ []
6. Bearings (removed, cleaned, checked for flaws) _____ []
7. Bearing housings (quality) _____ []
8. Antifriction bearings (high-quality and coated with oil) _____ []
9. Shaft sleeves (removed and checked for wear) _____ []
10. Alignment:
 - a. Vertical shaft movement of pump with sleeve bearings checked at both ends _____ []
 - b. End play allowed by bearings _____ []
11. Auxiliary piping:
 - a. Drains (checked and flushed) _____ []
 - b. Sealing-water piping (checked and flushed) _____ []
 - c. Cooling-water piping (checked and flushed) _____ []
12. Auxiliary coolers (flushed and cleaned) _____ []
13. Stuffing boxes (repacked) _____ []
14. Instruments (recalibrated) _____ []
15. Flow-metering devices (recalibrated) _____ []
16. Pump:
 - a. Tested for proper performance _____ []
 - b. Retested after all repairs _____ []

Piping Systems

Check the following items:

1. Repair torn or missing insulation on water and steam piping []
 2. Insulate piping, valves, fittings, and heat exchangers where heat is lost to unconditioned spaces or where heat loss from the pipes adds to the summer cooling load []
 3. Install insulation and a vapor barrier on cold water piping used for air-conditioning where the piping passes through uncooled spaces and picks up heat []
- Note: insulate hot piping that passes through unheated spaces where it can lose heat.
4. Protect pipe insulation from water and moisture to preserve its thermal resistance []
 5. Check for high temperature differences in heating and cooling heat exchangers, which may be an indication of air binding, clogged strainers, or excessive scale []
 6. Repair or replace leaky steam traps. Confirm the location of a leaking trap by testing the temperature of return lines with a surface pyrometer and measuring temperature drop across the suspected trap. Lack of drop indicates steam blow-through. Excessive drop indicates the trap is holding back condensate []
 7. Chilled water and hot water systems require almost complete elimination of air. Check vents before reducing water temperature to improve cooling performance or increase water temperature to meet room heating loads []

Terminal Units

1. Clean the air side of all direct radiators, fin tube convectors, and coils to enhance heat transfer _____ []
2. Keep radiators free from blockage. A 1-ft clearance in front of convectors, radiators, and registers is desirable. Heating systems, particularly hot water or electric baseboard radiators and low-level warm air supply registers work more efficiently if they are not blocked by furniture. Keep all books and other impediments from blocking heat or air delivery from the top of horizontal shelves or cabinets that enclose radiators, fan coils, unit ventilators, or induction units _____ []
3. If a radiator is directly in front of a window where the glass extends below the top of the radiator or in front of an uninsulated wall, insert a 1-in.-thick fiberglass board panel, with reflective coating on the room side, directly between the radiator and the exterior wall to reduce radiation loss to the outdoors _____ []
4. Vent all hot water radiators and convectors to ensure that water will completely fill the interior passages _____ []
5. Check radiator steam traps to ensure that they are passing only condensate, not steam _____ []
6. Make sure that all fans are running normally to maximize the transfer rate from heating coils _____ []
7. Use electric or infrared units as spot heaters for remote areas--a reception desk in a large lobby, for example--rather than operating an inefficient central system for a small area in the building _____ []
8. In public spaces of all buildings such as lobbies, corridors, stairwells, vestibules, and lounges, conserve energy as follows:
 - a. Where heat is provided by a unitary terminal equipment valve, turn off the equipment and remove the handles from control valves. If balancing cocks are included, turn them to the off position _____ []
 - b. In each stairwell of multistory buildings, shut off all but the unit located at the bottom _____ []
 - c. Turn off heat in vestibules and foyers _____ []
9. Overhead unit heaters should direct heat toward floors. Add directional louvers to focus heat toward the floor or areas requiring heat; where possible, draw return air from the floor _____ []

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